A ship hull and method of manufacturing such a hull

Field of the invention

The invention relates to a ship hull having a double hull, particularly for oil and chemical ships, passenger ships and fishing ships, as well as a method of manufacturing such a hull.

Background of the invention

Ship hulls of today for merchant ships are without exception built as single or double hulls from plates on frames, stringers and longitudinals, regardless of the field of use. However, in order to obtain increased security, international rules has pushed the evolution towards double hulls. A typical distance between the outer hull and the inner hull is less than approximately 3 m. A framework is arranged between the hulls.

Although double hulls have evidently resulted in significantly increased security at low energy ground impacts, the solution is far from optimal. The construction is significantly more expensive, and the lack of counter pressure from the water on the inner hull give rise to tension problems, whereas the significantly larger total plate area, which is approximately 2,5 times larger than for a single hull, give rise to increased corrosion problems and increased maintenance costs. At mechanical stress on the outside of the outer hull, it is heavily deformed locally, resulting in cracks in the steel plate. Moreover, the deformation is transferred by means of a framework between the hulls further on to the inner hull, which may also crack, resulting in leakage. In Fig. 1, such a hull is schematically illustrated comprising an outer hull 100, an inner hull 102, and a framework 104 arranged there between. When colliding with an external object, herein illustrated as an object 106 having a conical tip, a very local deformation of the outer hull 100 occurs, which quite rapidly may result in a

fracture or penetration 108.

Further, there is an explosion risk due to the formation of gas between the outer and inner hulls as low viscous substances from the oil or similar is pressed through cracks and welding air holes due to the lack of a counter pressure, in contrast to single hulls when the water applies a counter pressure from the outside of the ship. Therefore, the space between the hulls must be filled with inert gas, resulting in increased costs and the risk of leakage, as well as difficulties when inspecting the ship between the hulls.

Hence, there is a great need for an improved ship hull having a reduced or eliminated risk of cargo leakage at ground impacts and collisions.

There is also a great need for a ship hull having improved buoyancy, alternatively being unsubmersible at ground impacts and collisions. This applies to tanker ships but also particularly passenger ships for evident reasons.

In EP-B1-473587, a method is described of providing an improved hull, where sheets or mats made from a cellular plastic material are glued on an aluminium hull, and a glass fibre layer is applied thereon. This method results in a series of benefits and possibilities. Old rust-damaged or corroded hulls can be reconditioned in a simple manner. Thermal insulation is obtained, resulting in numerous advantages of manufacture in the field of yachts since the condensation problems are eliminated, among other things. Moreover, a sound-absorbing property is obtained in both directions. Further, the cellular plastic material is capable of absorbing energy which will protect the metal hull and provide increased local stiffness.

WO 02/43954 A1 generally discloses the manufacture of various layered composite structures, and it is mentioned that an inner layer and an outer layer of metal having an intermediate plastic material can be glued together, for use in the building of ships. However, the problems of external strain on a ship resulting in local deformation and penetration of the outer hull followed by leakage, are not dealt with herein.

Summary of the invention

Thus, it is an object of the present invention to provide a ship hull having improved deformation properties in the case of ground impacts and collisions, such that the risk of leakage is eliminated or at least substantially reduced.

Another object of the present invention is to provide a ship hull having improved buoyancy. Even in a damaged condition, it should float such that an oil cargo can be pumped over to another ship, or such that passengers can be evacuated from the disabled vessel.

A further object of the present invention is to provide a method of manufacturing a ship hull having improved deformation properties and an eliminated or at least substantially reduced risk of leakage in the case of ground impacts and collisions.

A further object of the present invention is to provide a method of manufacturing, or alternatively rebuilding a ship hull, making ships having this hull practically unsubmersible.

A further object of the present invention is to provide a method of manufacturing a ship hull that, regardless of hull shape, provides optimal fixation between different layers of the hull with a minimum of costs and without requiring accurate adjustments, such as e.g. mechanical measures in the form of

grinding, cutting, or the like.

Surprisingly, it has turned out that these objects and others can be obtained by means of the ship hull according to the present invention having the essential features presented in the characterising part of claim 1, and by means of the method according to the present invention having the essential features presented in the characterising part of claim 12.

In particular, the invention refers to a ship hull, especially intended for oil and chemical ships, passenger ships and fishing ships, comprising an inner hull made of steel or aluminium built on a supporting structure of frames, stringers and longitudinals, and an outer hull. Between the inner hull and the outer hull a cellular plastic material is applied having chiefly closed cells for improved buoyancy and energy absorbing capability. The outer hull is made of a high strength steel, wherein at external strain the outer hull and the cellular plastic material are adapted to jointly constitute an energy absorbing deformation zone. The specific properties of the cellular plastic material entail that the deformation arising from the indentation of the outer hull at collision can be rapidly distributed over a fairly large area around this indentation. Then, a counter-pressure in the cellular plastic arises which, in combination with the high strength steel material of the outer hull, entails distribution of the indentation over a fairly large surface, such that a heavy local deformation of the outer hull is avoided.

According to a preferred embodiment, the outer hull and the cellular plastic material are adapted such that in the case of external strain, said deformation zone absorbs enough stress to make the inner hull collapse or break before the outer hull.

The thickness of the cellular plastic material should preferably be adapted to the total weight of the ship in order to obtain buoyancy. The thickness of the cellular plastic material should preferably be selected within the range of 0,05-3,0 m and the thickness of the high strength steel should preferably be selected within the range of 0,005-0,030 m.

The cellular plastic material may be expanded polypropylene, expanded polythene, expanded PVC, expanded polystyrene, expanded PET, cross linked or non-cross linked materials, and preferably a particle foam of expanded polypropylene (EPP), optionally having a thermosetting plastic as the adhesive, or merely being heat welded together. Further, stiffeners may be arranged in the cellular plastic material, or a correspondingly enhanced stiffness in one direction in the cellular plastic material.

The cellular plastic material may be glued on the outside of the inner hull. The outer hull may further be glued on the cellular plastic material. The glue used is preferably a glue that forms a dilatation joint during hardening.

Further, at least one highly elastic layer, functioning as a membrane, may be arranged between the inner hull and the outer hull. The material in the highly elastic layer may be rubber, an elastomer or a polymer. The highly elastic layer may be formed by a glue used for gluing together the hull and the cellular plastic material.

The present invention further encompasses a method of manufacturing a ship hull according to the above, comprising an inner hull made of steel or aluminium built on a supporting structure of frames, stringers and longitudinals, and an outer hull. A layer of cellular plastic material mainly having closed cells is attached to the inner hull and a high strength steel

layer acting as the outer hull, wherein at external strain the outer hull and the cellular plastic material are adapted to jointly constitute an energy absorbing deformation zone.

According to the method, the outer hull and the cellular plastic material are preferably adapted such that in the case of external strain, said deformation zone absorbs enough stress to make the inner hull collapse or break before the outer hull.

Blocks of cellular plastic material with closed cells may be glued to the inner hull, and a steel plate may be glued to the cellular plastic material, wherein the steel plates glued to the cellular blocks can be welded together to form an outer hull. Blocks of a cellular plastic material having a glued layer of high strength steel can then be glued to the inner hull.

According to a preferred embodiment of the invented method, a construction may be provided between the inner hull and the outer hull fixing the hulls to each other at a desired mutual distance, however being weaker than said supporting structure of the inner hull, in order to form a gap. Alternatively, when rebuilding a double hull, an existing construction between the inner and outer hulls may be adapted such that said construction is weaker than the supporting structure of the inner hull. In the gap between the inner and outer hulls a cellular plastic forming material is injected in both cases, preferably cellular plastic spheres together with an adhesive, wherein said cellular plastic layer is formed attaching to the inner and outer hulls.

According to the method, the cellular plastic material layer is preferably designed with a thickness of 0,05-3,0 m and the outer hull is preferably designed with a thickness of 0,005-0,030 m.

The cellular plastic layer should be selected as having a

density of 60-400 kg/m^3 including the adhesive, appropriately at the most 200 kg/m^3, preferably 100-150 kg/m^3.

The inner surfaces of the hulls facing the gap may be pre-glued with a glue giving rise to a dilatation joint or visco-elastic glue joint, such as a dual component polyurethane glue, epoxy resin and moisture-hardening single component polyurethane glue or different types of prepegs.

Expanded polypropylene, expanded polythene, expanded polystyrene, expanded PET, expanded PPO, expanded PVC, or mixtures thereof may be selected for the expanded plastic spheres. A thermosetting plastic or any other hardening adhesive may be used as the adhesive.

Brief description of the drawings

The present invention is described in more detail below with reference to the appended drawings:

- Fig. 1 is a schematic section view of a prior art double hull structure when colliding with an external object.
- Fig. 2a is a schematic section view of a double hull structure according to the present invention during deformation when colliding with an external object.
- Fig. 2b is a schematic section view of the hull structure in Fig. 1 at a later stage of the deformation.
- Fig. 3a-c are schematic section views of different embodiments of the hull structure according to the present invention.
- Fig. 4 is a diagram illustrating variations of the force required to press a cone against different hulls during a collision process, dependent on the depth of indentation.
- Fig. 5 is a diagram illustrating the total amount of absorbed energy as a cone is pressed against different hulls during a collision process.

Detailed description of preferred embodiments

As mentioned above, Fig. 1 illustrates that heavy local deformation arises in the outer hull 100 at collision or ground impact, which may result in a break or penetration 108 quite rapidly and at a relatively low force of indentation.

Fig's 2a and 2b show a hull structure in accordance with the present invention, comprising an outer hull 200, an inner hull 202, and a layer of cellular plastic 204 provided there between. The hull according to the present invention is protected from leakage in plural steps. Jointly with the outer hull 200, the cellular plastic layer 204 forms an energy absorbing deformation zone, significantly increasing the local strength of the hull. The cellular plastic material in the layer 204 provides a considerable local increase of stiffness, at the same time increasing the global stiffness to some extent. Further, the outer hull 200 is made of a high strength steel, significantly contributing to the improved deformation properties of the hull, according to the below.

Fig's 2a and b illustrate schematically a collision with an external object 206, here illustrated as having a conic tip that is pressed against the hull structure. Practically, this may be a case of ground impact or collision with another ship or other object. Simulations have been conducted with different possible materials and dimensions of the included components, in order to study the course of deformation as a cone having a rounded tip is pressed against different hull structures, which is described in more detail below.

Thus, Fig. 2a illustrates that when the object starts to press against the outer hull 200, an indentation is formed therein, which however is counteracted by a counter pressure rapidly occurring in the cellular plastic material located just inside,

which is illustrated by means of plural opposite arrows. Due to the specific properties of the cellular plastic material, the deformation is spread rapidly therein over a fairly large area around the indentation. Thus, this counter pressure combined with the high strength steel material of the outer hull 200 results in that its indentation is distributed over a fairly large surface, such that a heavy local deformation in the outer hull is avoided.

Fig. 2b illustrates a somewhat later stage in the course of deformation as the object 206 has been further pressed inwards, when the indentation of the outer hull 200 is distributed over an increasingly large surface, due to the combined deformation properties of the outer hull and the cellular plastic material. In Fig. 2b, the deformation and pressure within the cellular plastic material have been spread out to such an extent that the inner hull 202 is also strained. Finally, it collapses or breaks, as shown in the figure, which however preferably occurs before the outer hull is penetrated by the object, which is possible due to the fact that the latter is not heavily deformed locally but over an increasingly large area.

Thus, the combination of properties of the cellular plastic material and of the outer hull is of crucial importance to the new hull system. The invention resides in the fact that the outer hull and the cellular plastic material are formed as an energy absorbing deformation zone, such that it will absorb enough stress to preferably make the inner hull collapse or break before the outer hull. A cellular plastic having a high yield point and progressive hardening module as combined with an outer layer having a high tensile strength and high permissible tensional force, provides for this desirable result. The company of SSAB, Luleå in Sweden produces and sells a high strength steel, named Domex 500, having the properties desirable for the

outer layer.

When the mechanical strain is so high that the inner hull is deformed, a breakage of the structure inside the inner hull occurs. Not until the deformation in the outer hull exceeds the tensile yield limit of the high strength steel, crack formation will occur, wherein leakage can still be prevented thanks to the sealing capability of the cellular plastic material.

According to a further development of the invention, a layer of a highly elastic material is provided between the inner metal hull and the hard metal surface layer, either adjacent to one of these or within the cellular plastic material. This highly elastic material can also be provided by means of a glue being used for gluing the cellular plastic material to the inner and/or outer hull. It is also possible to use both alternatives, as well as to provide plural membrane layers in the form of elastomers or thermoelastomers within the cellular plastic material. By providing a membrane together with the cellular plastic material, leakage is prevented also at a very severe indentation damage, since the highly elastic material will be released from the cellular plastic material in the damage area and follow the indentation, in order to spring outwards again thereafter and span any occurring cracks or holes. By dimensioning the materials in a suitable manner with respect to pressure and frequency, the structure can be optimised in order to obtain the desired properties. The material can also resist a pressure from a cargo within the ship, thereby preventing leakage due to cracks. In the case of tanker ships, the water pressure in the damage will interact with the cargo pressure. The same beneficial result is also obtained at an explosion damage inside the ship. A thickness within the range of approximately 2-10 mm can be expected to fully provide a satisfactory result. The material may be rubber, such as latex,

elastomers and polymers, but also soft metal compounds adapted for deep drawing will provide this result and will concurrently further contribute to an increased absorption of energy, and/or the membrane layer may be obtained by means of gluing the cellular material to any of the inner and outer hulls by using spacers between the materials during injection of the glue.

When the cellular plastic material is glued to a plate, the glue is preferably a glue that gives rise to a dilatation joint, at the same time being oil resistant, e.g. a dual component polyurethane glue. Other examples of glues that can be used are epoxy resins and moisture-hardening single component polyurethane glues, different types of prepegs.

The cellular plastic material should mainly comprise closed cells, and may be produced from various different types of materials, and also mixtures thereof, e.g. expanded polypropylene, expanded polythene, expanded PVC, expanded polystyrene, expanded PET. Depending on the requirements made, the materials may be cross linked or non-cross linked. A preferable embodiment is a particle foam of expanded polypropylene (EPP), optionally having a thermosetting plastic as the adhesive, or merely being heat welded together.

Further, stiffeners may be arranged in the cellular plastic material, or a correspondingly enhanced stiffness in one direction in the cellular plastic material.

Further, the cellular plastic material should preferably be flame-resistant, and in that case expanded graphite particles may be introduced in the particles and/or in the adhesive, which in the case of a fire will expand and form an incombustible layer. It is also possible to provide graphite as a layer united with the cellular plastic material, which then will include a

plurality of layers. The thickness and density of the cellular plastic material may differ depending on the current conditions, and may be within the ranges of, e.g., approximately 0,05-3m and 60-400 kg/m^3, respectively, normally approximately 100-150 kg/m^3.

The thickness and density of the cellular plastic material are significant for its function as a deformation zone and the desired energy absorption capability, but also for the buoyancy. By adapting thickness and density to the current prerequisites, the total weight of a ship can be completely counterbalanced and the ship will be unsubmersible.

When gluing the plates, it is also possible to use a prepeg material reacting at heat by hardening which can be supplied by means of an embedded electrical resistance material in the form of an etched foil, aluminium metal grid or some electrically conducting glue having a suitable resistance.

The hull structure according to the invention will automatically result in a number of significant advantages. The cargo spaces of the ship become thermally isolated and the need for additional heating or refrigeration is considerably reduced. In tanker ships of today, it is not sufficient to extract heat from the waste heat boilers in order to maintain the cargo at the lowest permissible temperature, but additional heat must also be supplied. Of course, the reverse situation is also relevant. For example, fishing boats transport a cold cargo instead, and by using a hull according to the invention the cooling needs will decrease drastically. It would be possible to transport warm cooling water from nuclear plants in insulated ships to users as a complement in municipal heating network systems.

According to another development of the invention, plural cellular plastic layers having different densities can be used,

by means of which a favourable heat insulating efficacy is combined with a favourable energy absorbing capability. For example, by providing an outermost cellular plastic layer having a higher density than an adjacent layer inside, the energy absorbing capability can be further improved.

Fig's 3a-c schematically show some different embodiments of the hull in accordance with the invention. Fig. 3a shows the hull in its most basic form having an outer hull 300, an inner hull 302 and an intermediate cellular plastic layer 304. In Fig. 3b, the hull comprises an inner cellular plastic layer 306, an outer cellular plastic layer 308, and a metal plate 310 located there between. The hull in Fig. 3c comprises an outer hull of a sandwich-type structure having two metal plates and an intermediate cellular plastic layer 312 of greater compactness than the remaining cellular plastic layer 314. However, The hull according to the invention is not limited to the shown exemplary embodiments, but can be provided with any number of metal plates and cellular plastic layers, of optional dimensions and choice of materials, within the scope of the essential features of the invention.

When the ship is dimensioned, the thickness of the hull plates are also determined in accordance with international classification rules. Using a high strength steel provides a saving of weight by permitting downsizing of thickness, at the same time still obtaining superior qualities such as a very high tensile strength at break during deformation due to ground impact, collision, explosion, etc.

A number of advantages are achieved by means of the hull according to the invention, as compared to the alternative known today of a conventional double hull having an intermediate framework, such as

- extremely good energy absorption capability,
- increased global stiffness of the hull,
- greatly increased local stiffness,
- extremely good insulation,
- significantly reduced risk for corrosion on the inside of the hull,
- higher loading capacity and higher buoyancy,
- significantly lower costs of maintenance,
- increased buckling resistance and local stiffness, and
- the possibility of converting existing single hull ships in a relatively simple manner.

The invention solves a great problem in a surprising manner. In spite of the extremely serious consequences of both tanker breakdowns and passenger ship breakdowns, the development of ship hulls has not progressed further than double hulls, which hardly improve the situation to any extent. The fact that improved buoyancy is obtained by applying a cellular plastic material on a ship hull may seem self-evident, but the fact that a hull according to the invention can be produced which, in addition, so radically changes the behaviour of the ship at collisions is all the more surprising.

The invention also refers to methods of manufacturing a ship hull according to the present invention, of which the essential features are presented in the independent claim 12. Further developments are presented in the dependent claims.

Basically, the method of the invention provides that a cellular material shall be connected to an inner and an outer plate hull. This can be made in several different ways by means of the common features that a cellular plastic material is connected to an inner hull and to an outer hull. Optionally, a membrane can

also be provided within or in connection with the cellular plastic material.

According to a preferred embodiment, the cellular plastic material in the form of blocks is glued to the inner hull. Thereby, the outer hull can be glued to the cellular plastic material in a subsequent step, or the outer hull can be first glued to blocks of the cellular plastic material which thereafter is glued to the inner hull.

According to a variant of the method of manufacturing the hull system according to the invention, sections of the cellular plastic material, which on the outside is provided with a high strength plate glued thereon, is provided on the inside with a milled-out groove around the periphery, into which a cellular plastic strip is depressed. This facilitates application of the block to the hull by vacuum suction during the pumping of glue between the surfaces to be glued together.

The membrane in the form of a highly elastic material can form a layer next to one or both of the hulls, and/or it can be applied between layers of cellular plastic material.

The outer hull can be welded together by means of reflecting backing bars located in grooves in the cellular plastic material, wherein the channels are filled after the welding by injection of a glue substance.

Alternatively, a recess is provided right under the joint area of the outer hull plate. In this recess, a strand of mineral wool is applied having the function of protecting the underlying material during the welding process. This strand can be left behind.

Starting with an inner hull conventionally built on frames, stringers and longitudinals, the working preferably begins at the bottom centre of the ship, and then continues upwards along the sides. The work begins with abrasive blasting and primer treatment of the hull. Thereafter, glue is applied jointly with a cellular plastic material, wherein the glue is advantageously applied on the cellular plastic material or on both surfaces. the cellular plastic material comes in the form of block. During assembly, the cellular plastic material is kept in position by means of a rubber film which is also used as coverage when the negative pressure is applied. During the hardening of the glue, a negative pressure is applied of approximately 0,3-0,4 kg/cm^2, thereby obtaining a pressure of 3-4 $tons/m^2$, which should be sufficient to reach a good result.

Alternatively, the cellular plastic blocks can be kept in position against the ship hull during the gluing by means of electromagnets, whereupon the glue is injected. The glue lines can be checked by means of ultrasonics.

According to yet another variant, the process may be as follows: A high strength plate of 1-3 mm is placed between cellular plastic blocks protruding from the ship side in the assembled state. These are preformed such that a great number of openings are punched in the plate, i.e., perforation. A fixture is made by means of a support from one side and a plunger from the other side, the plates are heated in an oven at a tried-out temperature, and are then sandwiched with the cellular plastic material which melts on the surface due to the temperature of the plate. When the fixture is filled up, the plunger crams the package, and the melted surface cellular plastic material will be joined through the perforations and be welded together. Further, various types of gluing against these plates may substitute the heat treatment. This embodiment may further

increase the deformation resistance and will create fire walls in the cellular plastic material. A lesser density of the cellular plastic material may aptly be used to counter-balance the plate weight.

In yet another variant of the method of manufacturing the hull system according to the invention, a construction is provided between the inner hull and the outer hull mutually fixing the hulls at a desired distance, but being weaker than said support structure of the inner hull, thereby forming a gap. Alternatively, during reconstruction of existing double hull ships, a construction already present between the inner and outer hulls is adapted such that said construction is weaker than the support structure of the inner hull. In the gap between the inner and outer hulls, a cellular plastic layer forming material is then injected, preferably cellular plastic spheres together with an adhesive, wherein said cellular plastic layer is formed and adheres to the inner and outer hulls.

It is essential that the structure keeping the outer hull at the desired distance from the inner hull is dimensioned such that it is deformed at a force less than a force giving rise to deformation of the inner hull. As a result, the cellular plastic can fulfil its function as an energy absorbing and energy distributing zone.

In the method of this variant, a number of essential advantages are obtained. Regardless of the shapes of the inner and outer hulls, optimal filling and attachment to the inner as well as the outer hull is achieved. Moreover, it is possible to vary the thickness of the cellular plastic layer by causing the gap between the inner and outer hulls to be differently sized at different positions in the ship, if needed.

during reconstruction of existing double hull ships, a construction is already present mutually fixing the inner and outer hulls mutually. These constructions can then be weakened in a suitable manner, preferably at locations typically subjected to ground impacts. At these locations, weaker plates can be welded in, in order to yield at damage and not be forced through the inner structure. The injected cellular plastic can then act in the intended manner. In double hull ships, the distance between the two plates is typically approximately 3 m. As a result, the cellular plastic layer will produce the desired function of distributing the forces at collision and ground impacts, respectively, at a low intensity, such as 60-150 kg/m^3, at the same time making the buoyancy quite great.

It is also possible that naval yards designed to build double hull ships can continue to do so, but with an adapted intermediate hull construction, such that the conversion costs of the naval yard can be minimised.

The system according to the invention has been subject to extensive testing and trials. Gluing tests have clearly disclosed that the surface layer of the cellular plastic material remains unaffected when the steel plate moves. Among other things, that is due to the fact that the glue is not hard after hardening. Thanks to the thickness of the cellular plastic material, the elasticity therein is so great that the influence on the glue joint is not critical, and as a result it is not absolutely necessary that the glue joint is elastic or visco-elastic.

Alternatively, the flame guard can be provided by mixing expanding graphite particles into the plastic material and/or the adhesive. A flame guard can also be arranged in the form of a layer of expanding graphite particles next to the inner hull,

i.e. in the glue.

Example

A PVC-foam having a density of 100 kg/m^3 can be loaded by 280 tons per m^2 before deformation occurs. This is the case without any surface layer on the top surface of the cellular plastic material. A PVC-foam having a density of 200 kg/m^3 can be loaded by almost 500 tons per m^2 before deformation occurs.

When deformation occurs, an outer layer is initially deformed, and in order to further deform the cellular plastic, the compressive force must be more than doubled. This fact combined with a hard surface layer on the cellular plastic surface which distributes a compressive force over a larger area, results in that the energy absorption capability of the structure according to the invention is extremely high.

When using expanded polypropylene or expanded polyethene, a further advantage is obtained in that, after compression, the cellular plastic material almost recovers its original thickness, however somewhat depending on the nature of the damage.

Yet another advantage gained by the invention relates to the problem of overgrowth and sea acorns in a salt water environment. In the convention of IMO regarding all ships and oil rigs, prohibition has been issued for environmentally harmful bottom paints containing tin and copper. However, no practically working alternative is currently available, and instead mechanical cleaning has been proposed.

Effective from January 2003, no painting with these materials must be done, and effective from January 2008, these paints must be removed or coated with an insulating paint. In the case of

tanker ships carrying a cargo of warm oil, overgrowth and sea acorns constitute a greater problem than for other ships. Double hulls have a relatively large distance between the outer and inner hulls, implying that air is circulated in this space (due to convection) together with a warm inert gas. As a result, the outer plate is kept warm, thereby promoting overgrowth. Thanks to the cellular plastic material according to the invention, the outer hull will get the same temperature as the water around the ship, and this will save large amounts of money for maintenance and propelling.

Finally, it should be mentioned that corrosion is a chemical process of which the speed increases with increasing temperature. Since the outside plate gets a lower temperature in the case of the hull system according to the invention, thanks to the insulating properties of the cellular plastic material layer, the length of life of the hull is substantially prolonged, possibly by several years.

Estimation of global characteristics

Since no full scale ship yet exists on which the invention has been tried out, cautious calculations have been made to prove the effects of the new hull system as compared to a conventional single hull.

Energy dissipation

Energy dissipation occurs if the material is repeatedly subjected to loads exceeding the tensile yield limit for the material in question. Calculations performed indicate that strains in the cellular plastic due to flexing of the hull girder at sea, so called "sagging" or "hogging", amount to approximately 1/80 of the yield point of the cellular plastic material. Tensions resulting from water pressure, statistically and dynamically (slamming), amount to approximately ¼ of the

tensile strength in the cellular plastic material.

Thus, the hull system according to the invention has proven not to give rise to any problems concerning the global properties of the hull.

Energy absorption

The energy absorption of the hull is crucial for preventing hull breakage and leakage at breakdown. The breakdowns can be divided into different categories or scenarios, such as

- ground impact
    - sharp rock,
    - rounded rock,
    - slanting ground;
- frontal collision,
    - other ship,
    - bridge-pillar,
    - pier or platform;
- lateral collision,
    - different ship sizes,
    - different loading conditions,
    - bows configuration.

For example, in the case of a ground impact against a sharp or rounded rock, respectively, as well as frontal collision and lateral collision, the object of ground impact will be perceived by the structure, when using the hull system according to the invention, as a collision with a much larger object, since the outer plate deflects inwardly towards the cellular plastic material, and the cellular plastic material will provide a strongly increasing resistance as the cells are compressed, after which the inner hull also starts to deflect during withdrawal of the internal support structure. Hence, the structure will only buckle and deflect instead of, as in the

known structures with single or double hulls, penetration occurring in all cases, although possibly not in the case of ground impact with a slanting ground.

As mentioned above, since there is no full-scale ship, calculations have been conducted for the simulation of a collision damage. Calculations have been conducted with respect to an imaginary metal sphere of 2 m diameter, which is forced into the structure from the hull outside. In order to make the inner framework collapse in a conventionally built ship, a pressing force of 400 - 600 tons is required against the sphere. It should be noted that this is also the case for known double hulls. In order to achieve the same result for the hull structure according to the invention, using 90 cm of cellular plastic material and an outer hull of Domex 500 MC 10 mm, the corresponding force is approximately 6000 tons, that is, roughly 10 times as great force is required to make the inner supporting structure collapse.

Comparison of collision resistance

The hull system according to the invention will be considerably safer than a conventional double hull system, since it cannot be penetrated with equal ease. As being discussed above, the inner hull of the new hull system will collapse before the outer steel plate is penetrated. To illustrate that, simulated collision analyses have been conducted.

A rock was simplified as a cone (1 m radius) having a rounded tip, and its impact against the different hull systems (semi-statically and perpendicular against the hull) was analysed. Evaluation of the different analyses resulted in the expected collision process for the different hull systems, as schematically illustrated in graphs shown in Fig's 4 and 5. The continuous line is valid for the hull according to the

invention, and the broken line is valid for a known conventional double hull. The graphs in Fig. 4 illustrate how the force required to press a cone through each hull system, depends on the depth of indentation.

The hull system according to the invention: As indicated in items 1-5 below, the hull according to the invention is designed such that the inner hull breaks before the outer hull.

1. The outer hull is loaded to an ever increasing extent and deflects. The underlying compressed cellular plastic spreads the load and conveys it to the inner hull.
2. A supporting structure in the form of so-called "stringers" on the inner hull collapses.
3. The inner hull collapses, while the outer hull deflects further.
4. Wet frames begin to stiffen the structure as the cone contact radius increases.
5. A continuous absorption of energy, at the same time as the entire inner hull collapses. However, the outer hull is still intact.

A previously known hull system: As indicated in items 6-10 below, the hull breaks fatally already at a relatively low force.

6. The outer hull is loaded to an ever increasing extent and deflects by heavy local deformation.
7. Stringers inside the outer hull collapse and rupture.
8. The outer hull ruptures as the cone impacts the hull plate.
9. The cone makes the outer hull plate break and reaches the wet frames in the intermediate framework, which to some extent increases the stiffness of the hull.
10. The cone reaches the inner hull which is loaded until it finally ruptures as well and a fatal breakage occurs.

A measure of importance for impact strength is the total energy absorption of the impact. Fig. 5 is a graph illustrating the amount of energy being required to press a cone through a hull during a collision process for the different hull systems. To be precise, the curves in the graph show how much energy is absorbed as a cone is pressed through each hull. It is clearly evident that the invented hull according to the continuous line absorbs much more energy than the conventional hull at the same depth of indentation. Furthermore, the new hull can cope with a greater indentation without breaking.

Thus, the illustrated simulation trials show that a hull provided with the essential features of the invention is far superior to a conventional double hull, with respect to deformation properties at ground impacts and collisions. Thereby, the risk of leakage is eliminated or at least substantially reduced.

In fact, the cellular plastic material has the specific capability, at external strain against the outer hull, of rapidly providing a strongly increasing resistance as the cells are compressed. As a result, the outer hull will deflect inwards over a relatively large area, while the deformation in the cellular plastic is distributed and propagates to the inner hull. Heavy local deformation of the outer hull is thus counteracted by means of the inherent capability of the cellular plastic to produce a counter force. Materials and dimensions of the included components are preferably selected such that the inner hull collapses or breaks <u>before</u> the outer hull can be penetrated. Thereby, the outer hull can remain intact and leakage proof while considerable deformation energy is conveyed to the inner hull, such that leakage of e.g. liquid cargo out to the outside water, and/or of water into the ship, is completely avoided.

Many further benefits are also obtained "into the bargain" by means of the invention with respect to buoyancy, insulation, corrosion, maintenance, global stiffness, manufacturing, etc, as described above.

Of course, further modifications and combinations of the above-described embodiments are possible within the scope of the invention. Thus, the invention is not limited to the described embodiments only, but is generally defined by means of the following claims.